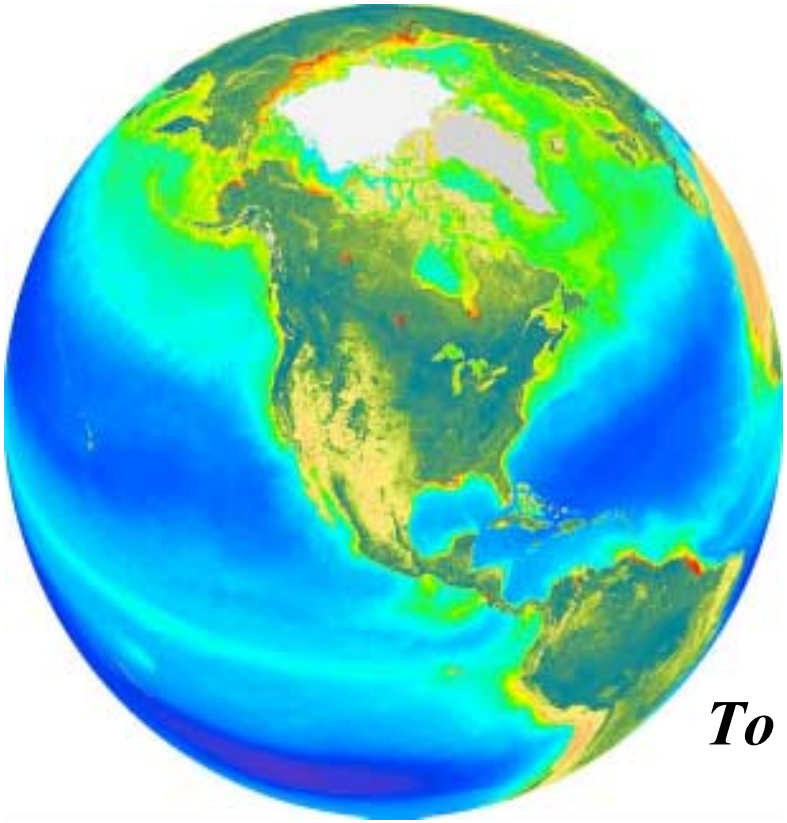
Terrestrial Ecology Program

NASA GSFC Site Visit

March, 2004

Diane Wickland & Bill Emanuel

The NASA Vision



To improve life here,

*To extend **life** to there,*

*To find **life** beyond.*

To understand and protect our home planet

*To explore the universe and search for **life***

*To inspire the next generation of **explorers***

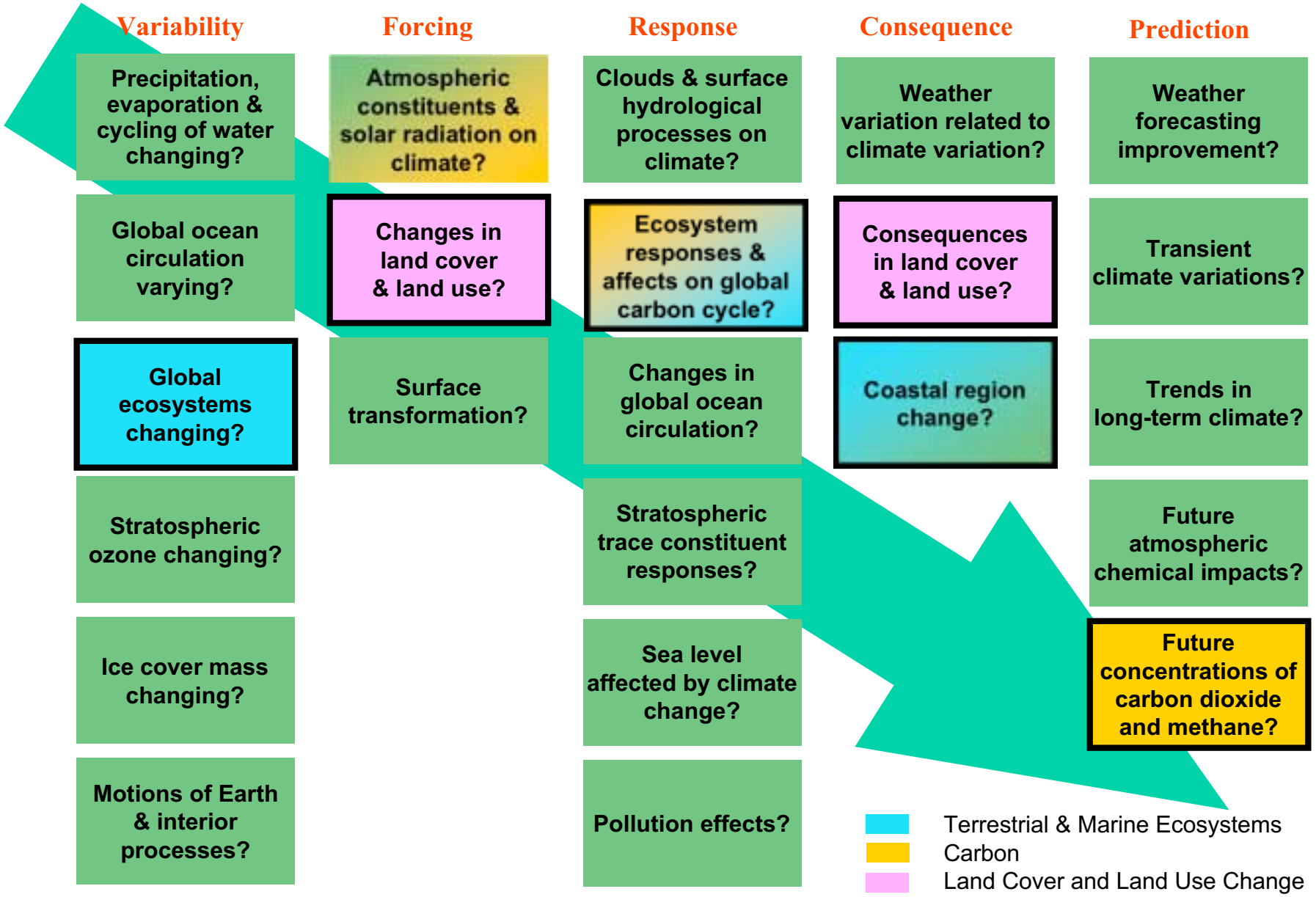
...as only NASA can.

Earth Science Research Questions

How is the Earth changing and what are the consequences for life on Earth?

- How is the global Earth system changing?
- What are the primary forcings of the Earth system?
- How does the Earth system respond to natural and human-induced changes?
- What are the consequences of change in the Earth system for human civilization?
- How will the Earth system change in the future and how can we improve predictions through advances in remote sensing observations, data assimilation and modeling?

Science Questions in the Research Strategy



ESE National Applications

Carbon Management

Public Health

Energy Management

Aviation

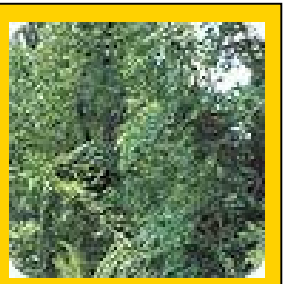
Water Management

Homeland Security

Coastal Management

Disaster Management

Agricultural Efficiency



Invasive Species

Ecological Forecasting

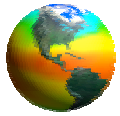
Air Quality

Draw upon carbon, ecosystems, and land use/cover science

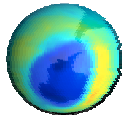
NASA Focus Areas & Program Elements

NASA Focus Areas

Climate Variability & Change

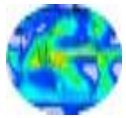


Weather

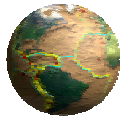


Atmospheric Composition

Carbon Cycle & Ecosystems



Water & Energy Cycle



Earth Surface & Interior

CC&E Program Elements

Land Cover & Land Use Change

Terrestrial Ecology

Ocean Biology & Biogeochemistry

R&A Program Elements

Ocean Biology and Biogeochemistry: Paula Bontempi & Carlos Del Castillo

Terrestrial Ecology: Diane Wickland & Bill Emanuel

Land Cover and Land Use Change (LCLUC): Garik Gutman

Biodiversity: **Woody Turner**

Carbon Cycle & Ecosystems Focus Area

Why is this Focus Area Important? *(Life)*

- Food, fiber, and fuel production (agriculture, forests & fisheries)
- Ecosystem goods & services (timber, pharmaceuticals, habitat, air & water quality)
- Carbon management (for climate mitigation and/or sustainability)
- Sustainability of uses *(to . . . protect our home planet)*
- Ecosystem Health
- Biodiversity

Carbon Cycle & Ecosystems Focus Area Research Questions (TE in green)

- How are global ecosystems changing? (V3)
- What trends in atmospheric constituents and solar radiation are driving global climate? (F1) *
- What changes are occurring in global land cover and land use, and what are their causes? (F2) *
- How do ecosystems, land cover, and biogeochemical cycles respond to and affect global environmental change? (R2)
- What are the consequences of land cover and land use change for human societies and the sustainability of ecosystems? (C2) *
- What are the consequences of climate change and increased human activities for coastal regions? (C3) *
- How will carbon cycle dynamics and terrestrial and marine ecosystems change in the future? (P4)

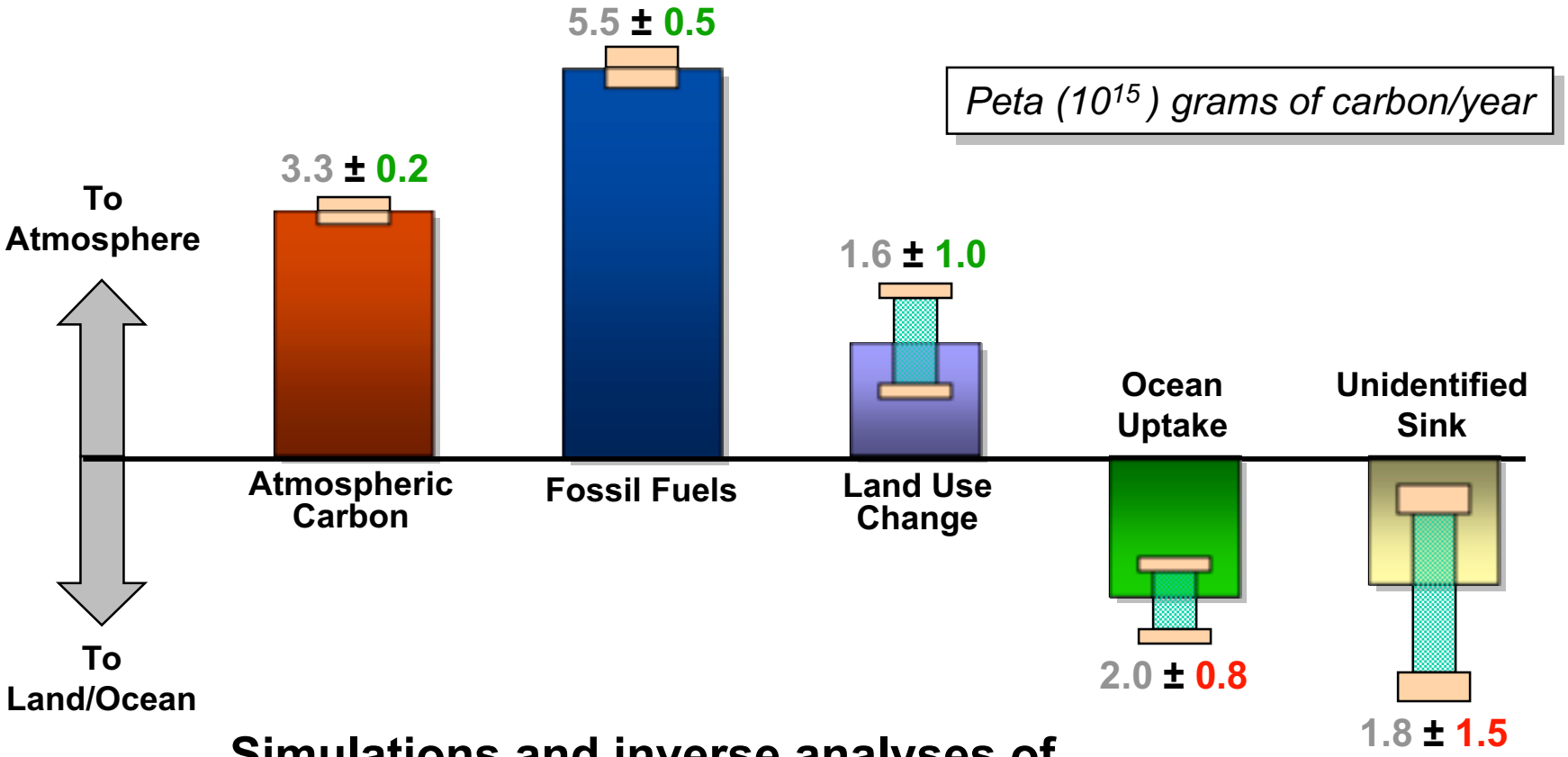
Terrestrial Ecology Program

Goal: to improve understanding of the structure and function of global terrestrial ecosystems, their interactions with the atmosphere and hydrosphere, and their role in the cycling of the major biogeochemical elements and water

Research Challenges

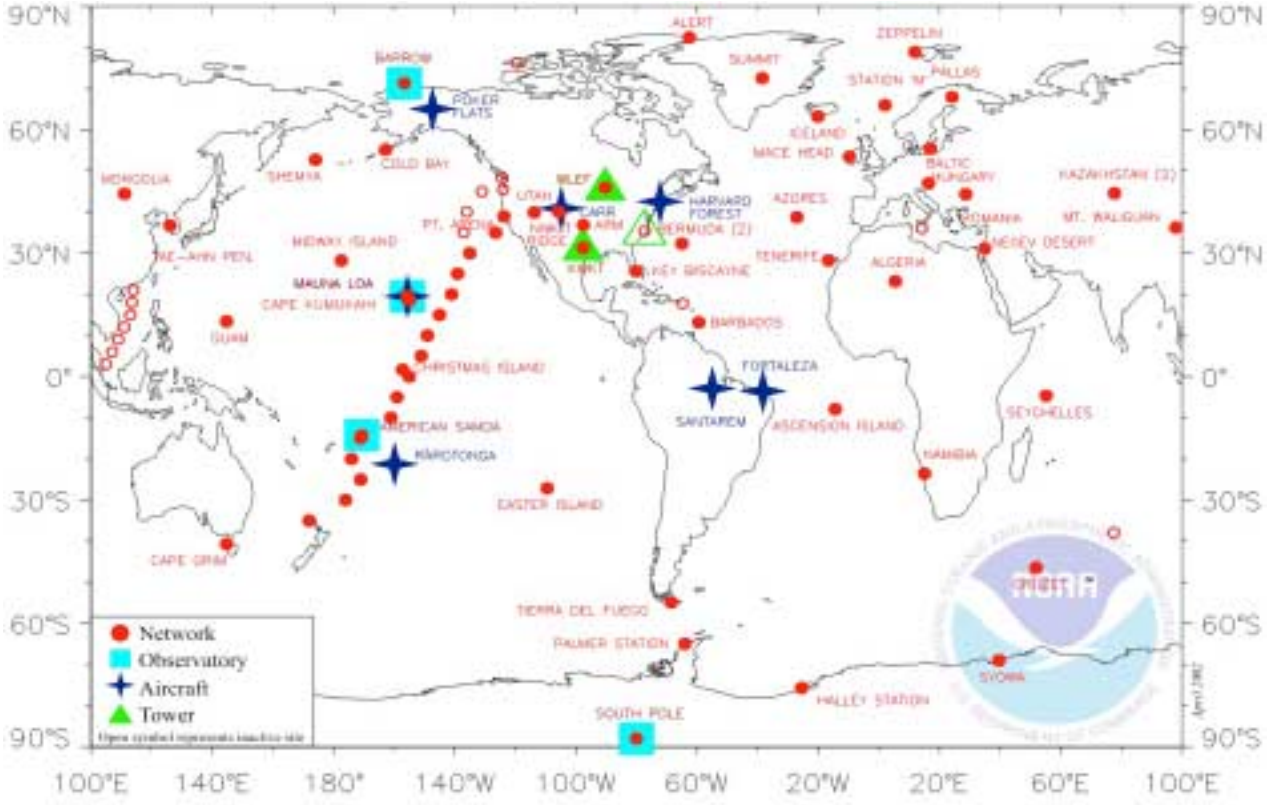
- Close the global carbon budget.
- Understanding the combined human and natural causes of land cover and land use changes and how these interact at regional and global scales.
- Understand the effects of multiple stresses on ecosystems.
- Develop remote sensing, spatial analysis, and information management tools to evaluate ecosystem management and mitigation, including options for responding to:
  - climate change
  - threats to sustainable resource use and the productivity of agricultural systems and coastal fisheries
  - changes in or loss of habitat and reductions in biodiversity
  - non-indigenous species invasions

Carbon Cycle Uncertainties



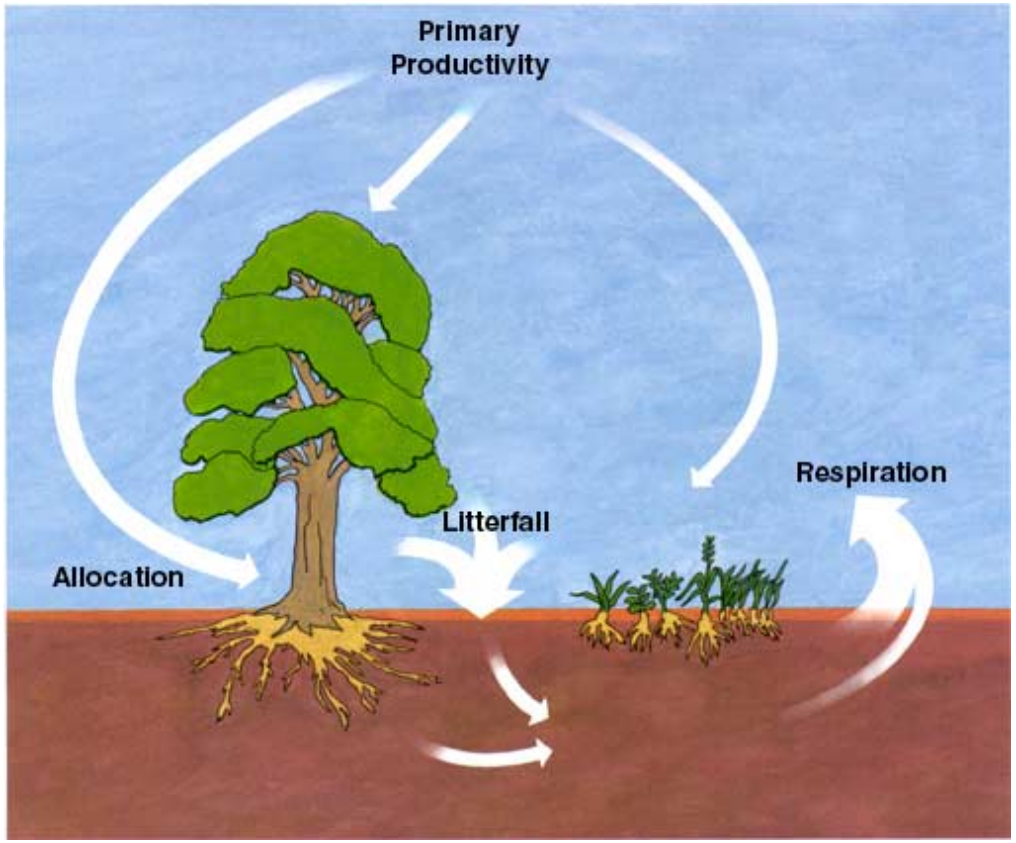
Simulations and inverse analyses of atmospheric observations indicate a sink for carbon on land in the Northern Hemisphere.

Sources and Sinks Derived from CO_2 Observations



Current CO_2 observations are sparse, particularly over land. Increased spatial and temporal resolutions by remote sensing can improve estimates of sources and sinks and our understanding of the processes involved.

Terrestrial Carbon Sink

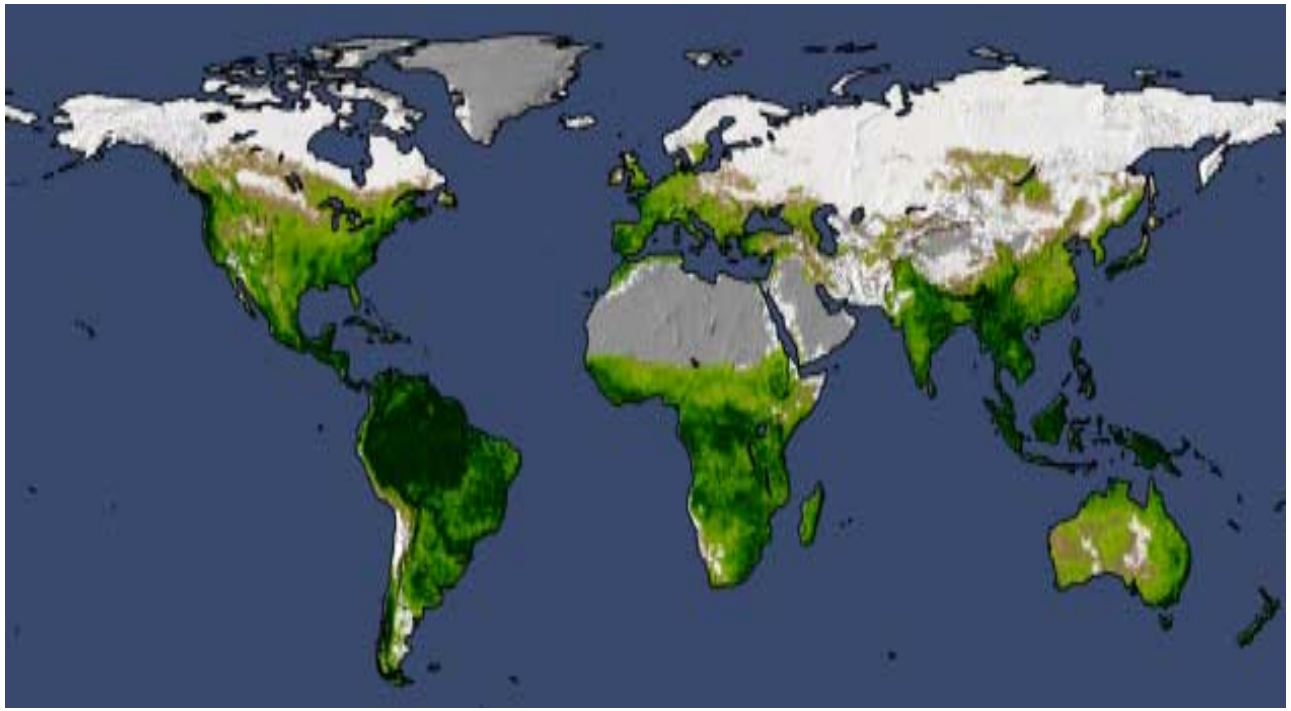


Revised from Post et al. (1995), © Sigma Xi

- CO_2 Increase
- N Deposition
- Climate Response
- Disturbance
- Recovery

Long-Term Observations

1999 Net Primary Productivity



Nemani *et al*., Science June 6, 2003

Long-term observations of productivity and related variables can estimate environmental influences on sources and sinks.

Disturbance and Recovery

Disturbances by human activities and natural events cause large, abrupt changes in carbon pools and initiate complex patterns of recovery.

In addition to high-resolution imagery, remote sensing of canopy vegetation structure and biomass is needed to estimate the associated carbon sources and sinks.

Major Terrestrial Ecology Program Activities:

Terrestrial Primary Productivity

Ecosystem Response to Change (incl. Disturbance/Recovery Processes)

Carbon Cycle Science

Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA)

Land-Atmosphere Interactions

Remote Sensing Science

Integrated Biogeochemical Cycles

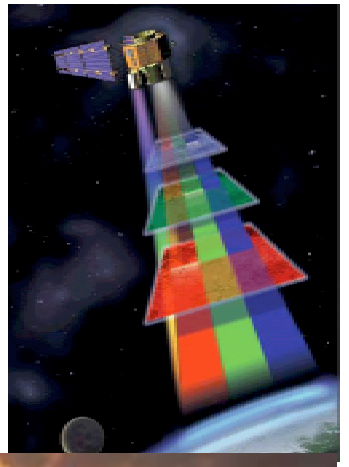
Minor activities from time to time: habitats & human health, ecosystem services, biodiversity, agricultural impacts/responses

NASA,s Role in LBA

- NASA provides the satellite observations essential for synoptic coverage of the vast and remote region of Amazonia.
- NASA's LBA research will contribute to U.S. Climate Change Science Program goals by reducing major uncertainties concerning tropical forest responses to climate and land use changes.
- NASA has the unique expertise and capability for conducting integrated, multi-disciplinary field campaigns combining remote sensing, spatial data analysis, field studies, and modeling.
- NASA's scientific and technical leadership in spatial scaling methodologies, Earth system modeling, and data and information management is critically needed in LBA.

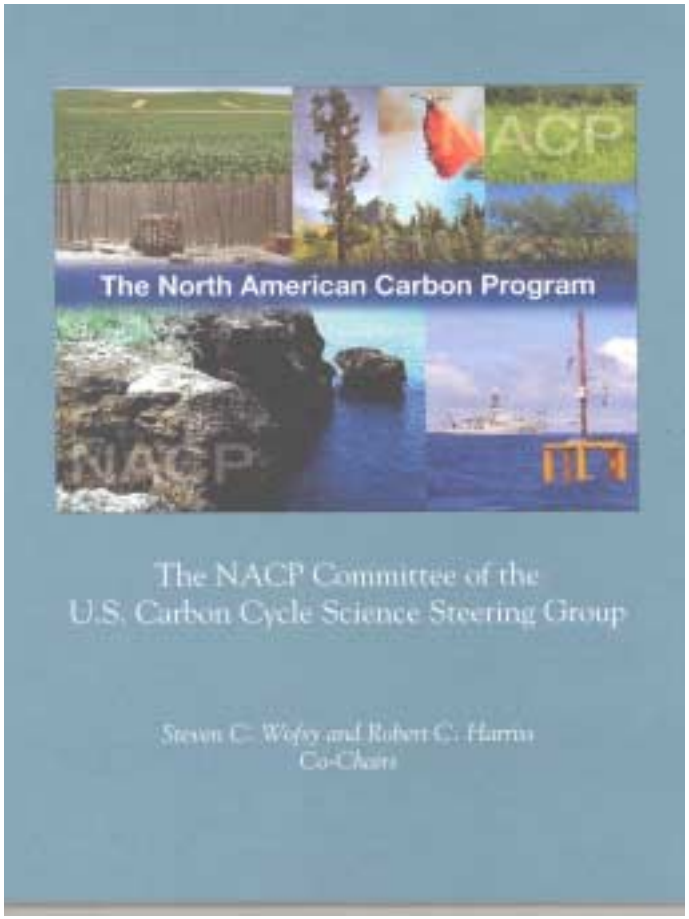
Mosaic of South America from MODIS on Terra

LBA: A Model for Earth Science Cooperation?



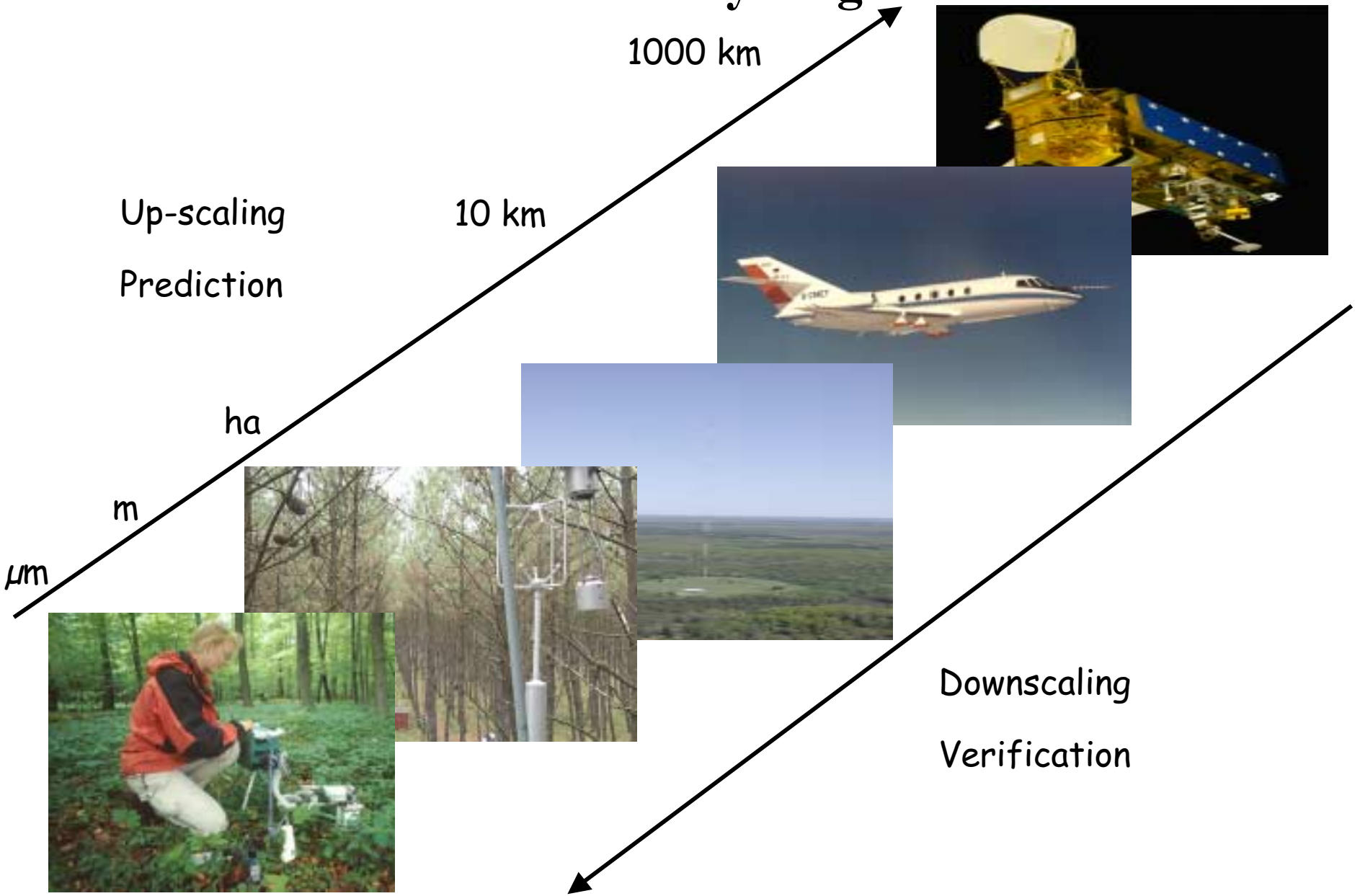
- Brazil as host and leader provides internal capacity and facilities
- NASA provides key expertise in remote sensing, modeling, organization and implementation of large scale field campaigns
- Other international partners provide funds and complementary expertise
- LBA has been taken as a model for International Geosphere-Biosphere Program (IGBP) regional studies

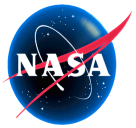
North American Carbon Program



The central objective of the North American Carbon Plan is to measure and understand the sources and sinks of CO_2, CH_4, and CO in North America and in adjacent ocean regions.

Integrated, Multiple Observational Constraints on Carbon Cycling





Carbon Cycle & Ecosystems

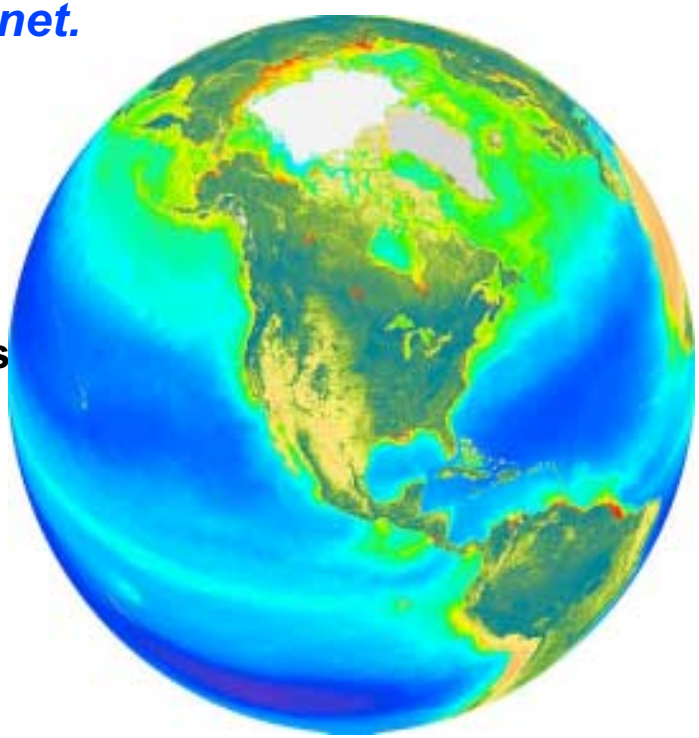
Roadmap Overview

Carbon Cycle and Ecosystems

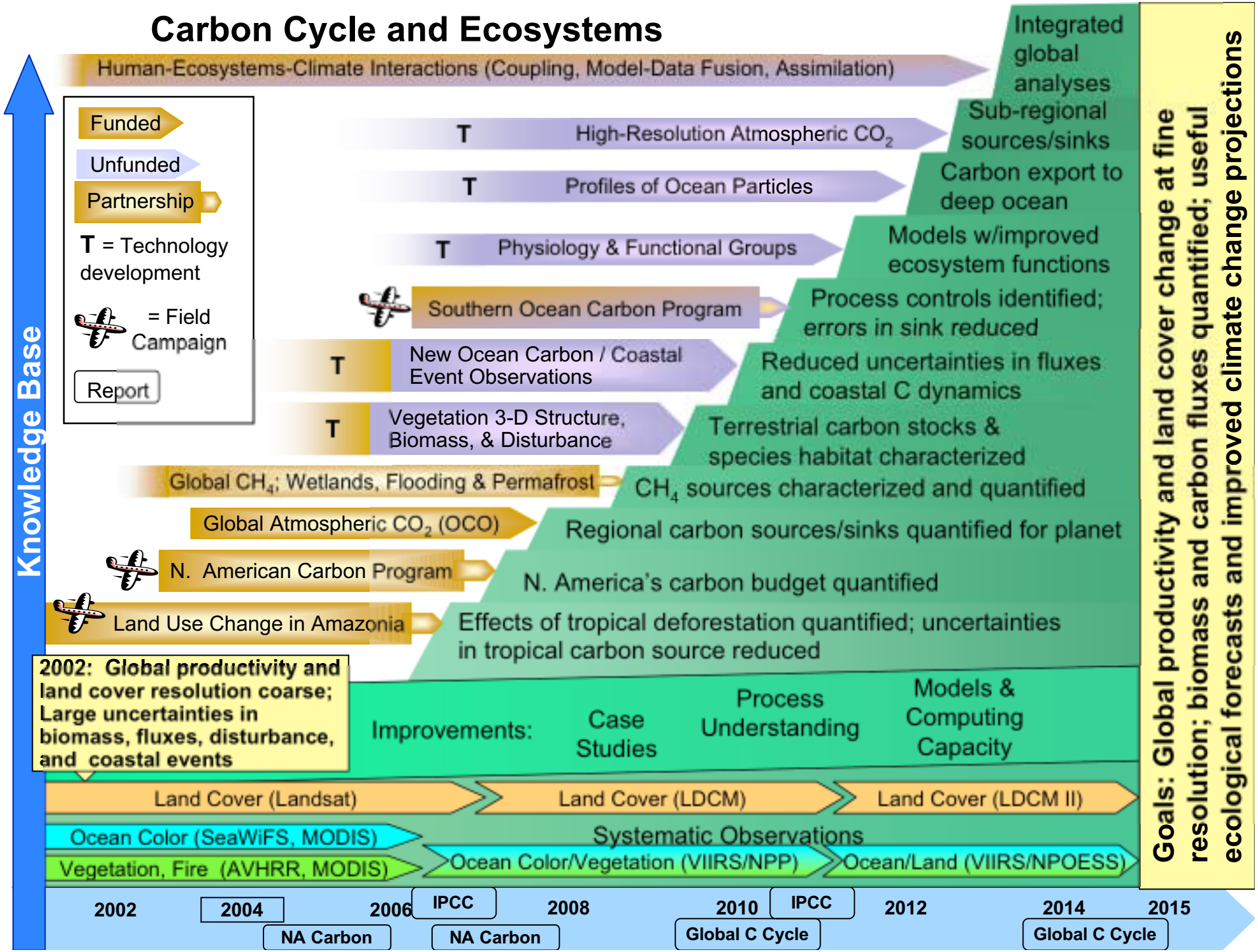
Knowledge of the interactions of global biogeochemical cycles and terrestrial and marine ecosystems with global environmental change and their implications for the Earth,s climate, productivity, and natural resources is needed *to understand and protect our home planet.*

Important Concerns:

- **Potential greenhouse warming (CO_2, CH_4) and ecosystem interactions with climate**
- **Carbon management (e.g., capacity of plants, soils and the ocean to sequester carbon)**
- **Productivity of ecosystems (food, fiber, fuel)**
- **Ecosystem health and the sustainability of ecosystem goods and services**
- **Biodiversity and invasive species**



NASA provides the global perspective and unique combination of interdisciplinary science, state-of-the-art Earth system modeling, and diverse synoptic observations needed to document, understand, and project carbon cycle dynamics and changes in terrestrial and marine ecosystems and land cover.


Carbon Cycle and Ecosystems
Knowledge Base
Human-Ecosystems-Climate Interactions (Coupling, Model-Data Fusion, Assimilation)
Integrated global analyses
Funded
Unfunded
Partnership
T = Technology development
= Field Campaign
Report
T
High-Resolution Atmospheric CO_2
Sub-regional sources/sinks
T
Profiles of Ocean Particles
Carbon export to deep ocean
T
Physiology & Functional Groups
Models w/improved ecosystem functions
Southern Ocean Carbon Program
Process controls identified; errors in sink reduced
T
New Ocean Carbon / Coastal Event Observations
Reduced uncertainties in fluxes and coastal C dynamics
T
Vegetation 3-D Structure, Biomass, & Disturbance
Terrestrial carbon stocks & species habitat characterized
Global CH_4; Wetlands, Flooding & Permafrost
CH_4 sources characterized and quantified
Global Atmospheric CO_2 (OCO)
Regional carbon sources/sinks quantified for planet
N. American Carbon Program
N. America's carbon budget quantified
Land Use Change in Amazonia
Effects of tropical deforestation quantified; uncertainties in tropical carbon source reduced
2002: Global productivity and land cover resolution coarse; Large uncertainties in biomass, fluxes, disturbance, and coastal events
Improvements:
Case Studies
Process Understanding
Models & Computing Capacity
Land Cover (Landsat)
Land Cover (LDCM)
Land Cover (LDCM II)
Ocean Color (SeaWiFS, MODIS)
Systematic Observations
Vegetation, Fire (AVHRR, MODIS)
Ocean Color/Vegetation (VIIRS/NPP)
Ocean/Land (VIIRS/NPOESS)
Goals: Global productivity and land cover change at fine resolution; biomass and carbon fluxes quantified; useful ecological forecasts and improved climate change projections
2002
2004
2006
IPCC
2008
2010
IPCC
2012
2014
2015
NA Carbon
NA Carbon
Global C Cycle
Global C Cycle

Anticipated Progress in Answering the Questions:

Forward

Where we are now	Where we plan to be
Global primary productivity and land cover time series available at coarse (~8 km resolution); only short time periods and certain regions at higher resolutions.	Decadal variability in global productivity quantified at moderate (~1 km) resolution; Periodic global land cover change analyzed at fine (~30 m) resolution.
Available observations (*in situ*) of global CO_2, biomass, plant community vertical structure, and species functional groups insufficient to resolve many issues.	New observations (space-based) enable quantification of carbon and nutrient storage and fluxes, disturbance and recovery processes, and ecosystem health.
Large uncertainties in N. Hemisphere terrestrial carbon storage, ocean uptake and storage, permafrost outgassing, and tropical land use effects. Global carbon budget not balanced.	Carbon sources and sinks identified and quantified at sub-regional scales (~100 km), with small errors. Global carbon budget balanced on annual basis.
Ecosystem and carbon models resolve only large year-to-year variations; multiple controlling processes not well quantified. 50-year projections vary widely.	Earth system models able to correctly portray most interannual variations and multiple, interacting controlling processes, with sub-regional specificity and useful predictive capability.

2002 ~ 2015

Anticipated Outcomes and Uses of Results

Predicting Carbon Cycling

Result / Capability	Products / Uses for Decision Support
Global primary productivity and land cover change time series variability and trends quantified at moderate to fine spatial resolution. Carbon sources and sinks identified and quantified.	Quantitative global **monitoring & evaluation tools**: to assess the efficacy of carbon management (e.g. sequestration in biomass); to assess agricultural, forest, and fisheries productivity; for use in verifying emissions and/or sequestration reporting by nations/sectors.
Quantification of carbon and nutrient storage and fluxes, disturbance and recovery processes, and ecosystem health. Quantification of controlling processes and their interactions.	**Maps, data products and information** on relationships among them as input for decision support systems. Simulation models that enable "If … , then…" scenarios to be explored.
Models that: - achieve carbon balance - reliably characterize interannual variability and sub-regional processes - quantitatively portray multiple, interacting controlling processes - are able to correctly simulate past land cover, ecosystem dynamics and biogeochemical cycling	**Ecological Forecasts**: Projections of changes in carbon sources and sinks, land cover, and ecosystem dynamics due to combinations of real-world forcings of global environmental change with sub-regional specificity and good reliability for ~6 mos. to 2 years into the future (e.g., harmful algal blooms, invasive species). --- **Inputs for Climate Projections**: Credible, useful projections of future climate change (including improved ecosystem feedbacks and projections of CO_2 and CH_4 concentrations) for 50-100 years into the future for a variety of policy-relevant "if …, then …" scenarios.

Anticipated Outcomes — Carbon Cycle

- Realistic estimates of carbon sources and sinks and ecosystem response scenarios, derived from improved models assimilating a larger, more accurate suite of observations.

- Validated, synoptic global data products that quantify:
  - Ecosystem productivity and carbon storage,
  - Ecosystem responses and feedbacks to climate change,
  - Changes in land cover and land use.

Anticipated Outcomes — Carbon Management

- Measurements / estimates of carbon storage — especially sequestration in biomass, soils, and the coastal zone — for assessment of sequestration projects, carbon accounting, and/or carbon credits.

- Global measurements of atmospheric CO_2 for use in locating and quantifying regional carbon sources and sinks (for carbon accounting, verification of national/regional estimates produced using inventory-based approaches).

- Decision support tools for managing carbon uptake and release by ecosystems in the context of multiple uses/benefits and best practices.

Anticipated Outcomes — Resource Management

- Monitoring, modeling, and decision support tools to:
  - Inform crop planning and rotation and fisheries management,
  - Assess and mitigate the effects of invasive species,
  - Assess the effects of land cover and land use change for regional, urban, and coastal zone planning,
  - Manage active fires and assess post-fire consequences and recovery processes,
  - Assess economic and public health risks associated with changes in terrestrial and marine ecosystems.

Anticipated Outcomes — Predictions

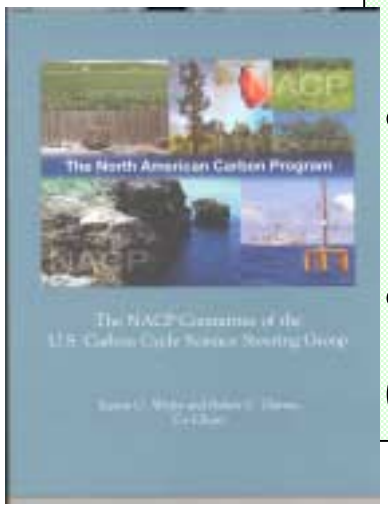
- Realistic projections of trajectories of change and future consequences, derived from improved models with mechanistic processes and driven by remote sensing data, including:
  - Estimates of future atmospheric CO_2 and CH_4 concentrations,
  - Trajectories of future land cover/use change,
  - Forecasts of the initiation, path, landfall, and evolution of harmful algal blooms,
  - Forecasting systems for potential outbreak and spread of non-indigenous invasive species,
  - Forecasts of changes in species distributions, habitat, and biodiversity.

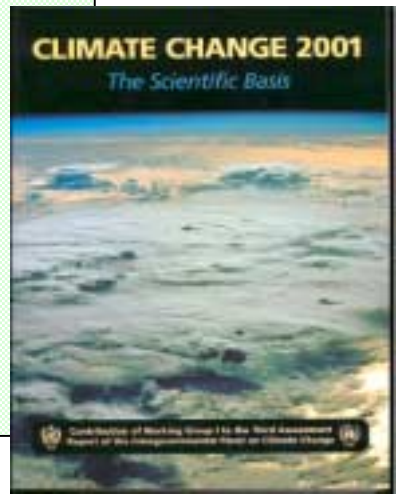
Assessments and Periodic Reports

Carbon/Eco/Bio Roadmap

NASA will supply information on carbon sources and sinks, ecosystems, and land cover and land use change, including global data products and model projections, for use in national and international assessment activities.

- **Intergovernmental Panel on Climate Change (IPCC)**
- **Millennium Ecosystem Assessment**
- **North American Carbon Report**
- **State of the Carbon Cycle Report (SOCCR, aka SAR 2.2 of CCSP)**





Carbon Cycle & Ecosystems: Outcomes (Performance Indicators for GPRA)

Proposed New Outcome 1.1.6: ***Develop projections of future atmospheric concentrations of carbon dioxide and methane for 10-100 years into the future with improvements in confidence of >50% by 2014.***

Proposed New Outcome 1.1.7: ***Develop, in partnership with other agencies, credible ecological forecasts that project the sensitivities of terrestrial and aquatic ecosystems to global environmental changes by 2014 in resource management and policy-related decision making.***

- ***Proposed New Outcome 1.1.8:*** ***Report changes in global land cover, productivity, and carbon inventories with accuracies sufficient for use in the food industry, in evaluating resource management activities, and in verifying inventories of carbon emissions and storage.***

Analysis of Program from June, 2003 Focus Area Review

Carbon Cycle & Ecosystems: Priorities for Next 5 Years

- Climate Data Records (CDR's) - which parameters, accuracy and precision requirements; community consensus products; multi-sensor validation
- Continental-scale high spatial resolution land cover products
- North American Carbon Program (land-atmosphere-ocean)
- Coastal focus - measurement requirements, cal/val, geostationary
- Preparation for OCO ESSP mission (validation, model development, data fusion)
- Model-data fusion and data assimilation
- Evaluating science requirements/measurement options for vegetation structure
- Advanced remote sensing and *in situ* concepts - platforms (satellites, aircraft, UAV, AUV, moorings), sensors (LIDARS, hyperspectral, inherent and apparent optical properties, genetic markers, fluorescence)

Climate Data Records for Carbon Cycle & Ecosystems

Climate Data Records:

Global Ocean Color CZCS/SeaWiFS/MODIS/VIIRS Quantitative, bi-weekly - monthly estimates of chlorophyll a, primary productivity, sea surface temperature, aerosol optical thickness; improved prediction of harmful algal blooms; quantification of ecosystem response to climate change.

Global Terrestrial Vegetation Index and Biophysical Properties (LAI, fAPAR) needed to estimate terrestrial NPP AVHRR/MODIS/VIIRS Quantitative, bi-weekly - monthly estimates of primary productivity; improved estimates of stress, yields; improved famine early warning; monthly estimates of key ecosystem parameters for global ecosystem and climate models.

Land Cover and Land Cover Change AVHRR/MODIS/VIIRS and Landsat/LDCM Global measurements of the areal extent of important land cover and vegetation types; quantification of the areal extent and nature of changes in land cover

Candidates for Climate Data Records:

Global Fire Occurrence AVHRR/GOES/MODIS Improved fire-fighting efficiency; improved enforcement of burning/clearing regulations; improved assessment of illegal logging

Burned Area AVHRR/Landsat/MODIS/VIIRS/LCDM Quantitative areal estimates of burned areas; improved estimates of carbon and aerosol emissions

Inundated wetlands L-band SAR on JERS-1/ALOS Quantitative estimates area and duration of inundation by water in forested and other wetlands (ours to encourage, not produce?)

Needed Inputs, Outputs, and Outcomes

From Space:

• Continuity of land cover, ocean color, and vegetation biophysical properties data stream w/time series data quantitatively intercomparable (near- and long-term)

• New measurements and evaluation tools; we have ambitious aspirations and options for choices based on future state of science and technology (longer-term);
➔ *past strategies have had somewhat frustrating outcomes*

From Suborbital and Field Campaigns:

• In-depth, comprehensive data sets focused on specific Carbon Cycle & Ecosystems questions to achieve major leap forward in scientific understanding (e.g. reducing major uncertainties), developing methodologies for interpreting satellite data, and identifying and quantifying process controls to improve remote sensing-driven carbon cycle, ecosystem and land cover/use change models.

• Airborne platforms and sensors to provide measurements at intermediate scale (between *in situ* and space-based) for: satellite sensor validation, testing of new measurement capabilities, unique scientific information (near- and long-term)

Needed Inputs, Outputs, and Outcomes

From Other ESE Focus Areas / CCSP Program Elements:

- Global climate data products (e.g., surface temperature, precipitation, soil moisture (rooting depth!), sea surface winds, salinity, freeze/thaw dynamics) for modeling
- Improved ocean circulation and atmospheric transport models
- Shared investment and analyses in *in situ* observations for validation/field campaigns/improved sampling (e.g., ocean moorings/drifters/ship-based surveys, CO_2/H_20 fluxes, case studies of land management)
- Shared scientific and technical expertise on cross-disciplinary problems (e.g., w/Atmospheric Composition for measurement & analysis of CO_2 and CH_4, with most others for improved model coupling and evolution toward fully interactive Earth system models)